Authors wanted!

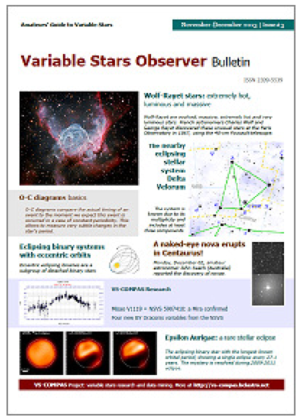
We invite authors and amateur researchers to publish their articles in the Variable Stars Observer Bulletin. If variable stars is your passion and you have something interesting to say to the community – go ahead and contribute! No matter whether your article is a strict scientific text reporting your advanced research results or just an overview article for amateur reading – it works. Amateur astronomy has a good commitment to the science for generations, and there is always a need in a good reading for people who are just on their way to the big science. Or just want to be in the context of contemporary progress in astronomy.

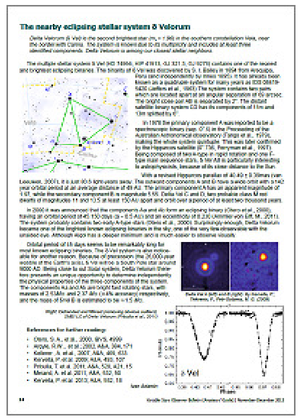
Pure scientific texts often require a solid background in math and astrophysics, but what we can do is to create a simplified overview of those papers. This intention follows a very clear goal: to provide a simple join-point for amateurs to advanced scientific research, taking into account their basic experience. For those who are interested in further reading, there are always a list of recommended publications or web references to continue with.

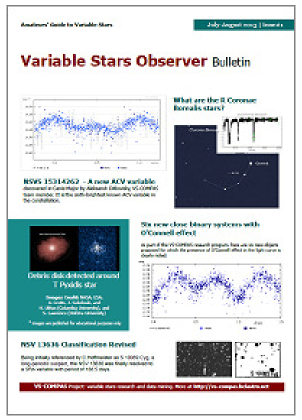
Authors making research in the field of variable stars are welcome to publish their articles in the following issues! Should you have an article ready for sharing with the community, just contact us, so we can schedule it.

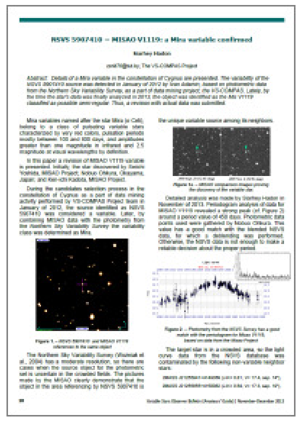
This year is just a start. We prepared three issues, so everyone can check out the overall concept behind the project. Do not hesitate to forward your questions to vs-compas@belastro.net.

Merry Christmas and Happy New Year to everyone! Clear skies...









The VS-COMPAS Project

The project was started in fall of 2011 by four amateur astronomers from Belarus. The main intention is to expand the International Variable Star Index (VSX) catalog with new variable stars, variable stars data analysis and research. Among the most significant achievements it is worth to mention more than 1200 variable stars discovered by combined efforts of seven active team members. All data about discovered stars is submitted to the VSX catalog running by the AAVSO. Another valuable goal the project has is increasing public interest to variable stars science.

More information about the team and discoveries can be found at http://vs-compas.belastro.net

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Variable Stars Observer Bulletin

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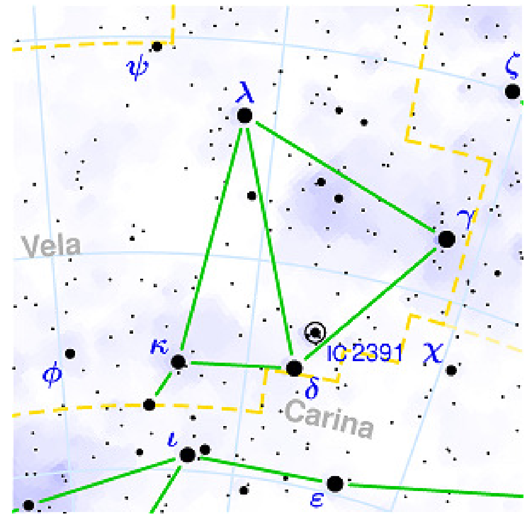
Wolf-Rayet stars: extremely hot, luminous and massive

Wolf-Rayet are evolved, massive, extremely hot and very luminous stars. French astronomers Charles Wolf and George Rayet discovered these unusual stars at the Paris Observatory in 1867, using the 40-cm Foucault telescope.

The nearby eclipsing stellar system Delta Velorum



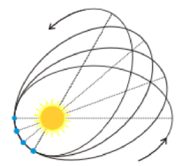
The system is known due to its multiplicity and includes at least three components.

O-C diagrams basics

O-C diagrams compare the actual timing of an event to the moment we expect this event is occurred in a case of constant periodicity. This allows to measure very subtle changes in the star's period.

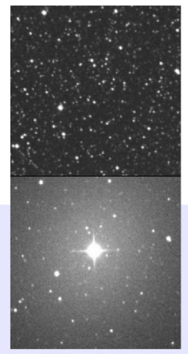
Eclipsing binary systems with eccentric orbits

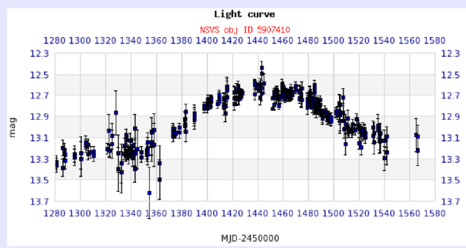
Eccentric eclipsing binaries are a subgroup of detached binary stars



A naked-eye nova erupts in Centaurus!

Monday, December 02, amateur astronomer John Seach (Australia) reported the discovery of novae.

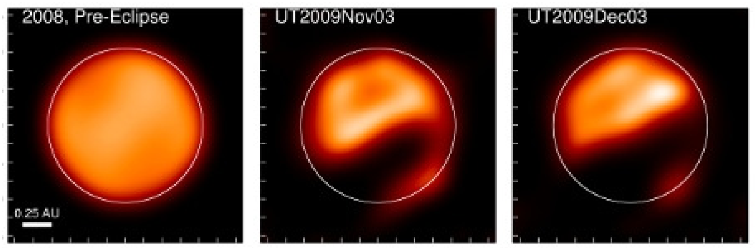




VS-COMPAS Research

Misao V1119 = NSVS 5907410: a Mira confirmed

Four new BY Draconis variables from the NSVS



Epsilon Aurigae: a rare stellar eclipse

The eclipsing binary star with the longest known orbital period, showing a single eclipse every 27.1 years. The mystery is resolved during 2009-2011 eclipse.

VS-COMPAS Project: variable stars research and data mining. More at **http://vs-compas.belastro.net**

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Amateurs' Guide to Variable Stars

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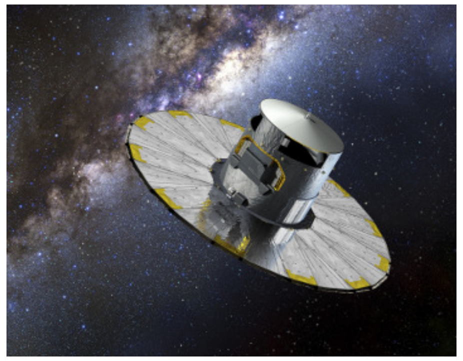


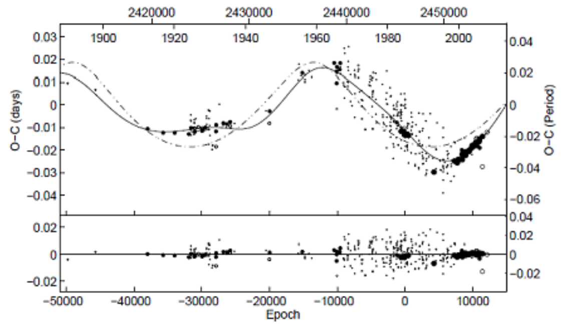
The five-year-long space trip of the telescope named Gaia started from Kourou in French Guiana on Thursday, December 19, 2013 at 9:12 UTC, where it was taken off on top of a Russian-built Soyuz-Fregat launch vehicle.

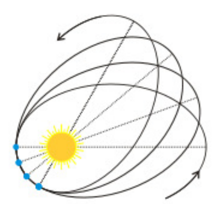
Delta Velorum is the second brightest star in the constellation Vela, near the border with Carina. The system is known due to its multiplicity and includes at least three components. Delta Velorum is among our closest stellar neighbors.

Wolf-Rayet are evolved, massive, extremely hot (up to ~50,000 K) and very luminous stars, 10^5 to 10^6 times brighter that of the Sun. Wolf-Rayet stars are named after Charles Wolf and George Rayet, French astronomers who discovered these unusual stars at the Paris Observatory in 1867.

Epsilon Aurigae is the fifth brightest star in the northern constellation Auriga. It is the eclipsing binary star with the longest known orbital period, showing a single eclipse every 27.1 years. For the last two centuries the nature of the eclipsing object was not reliably explained, until its long-awaited eclipse in 2009-2011.

Most variable stars change its brightness over a cycle. O-C diagrams compare the actual timing of an event to the moment we expect this event is occurred in a case of constant periodicity. By building O-C diagrams one can measure very subtle changes in the star's period.

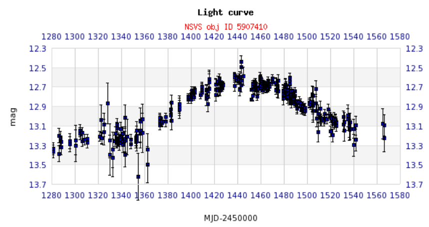




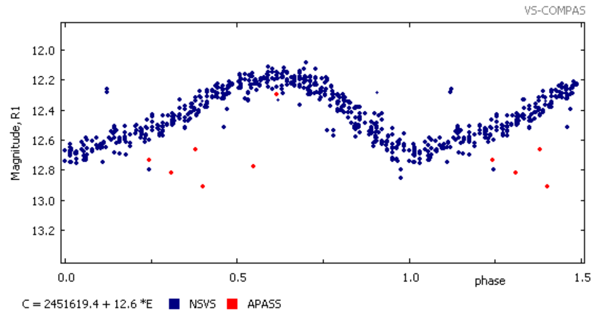
Eccentric eclipsing binaries are a subgroup of detached binary stars that have provided new and important information for the study of internal stellar structure. Eccentric systems display the phenomenon of Apsidal motion, allowing to get valuable astrophysics parameters of the binary system.

On Monday, December 02, amateur astronomer John Seach from Chatsworth islands of New South Wales (Australia) reported the discovery of a new star (5.5m) in the constellation Centaurus, not far from Beta Centauri.

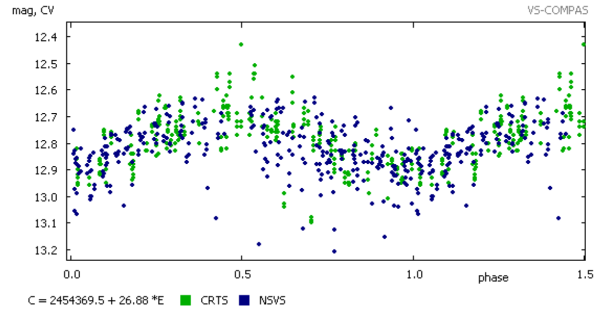
Details of a Mira variable in the constellation of Cygnus are presented. The variability of the NSVS 5907410 source was detected in January of 2012. Later, the object was identified as the Mis V1119.



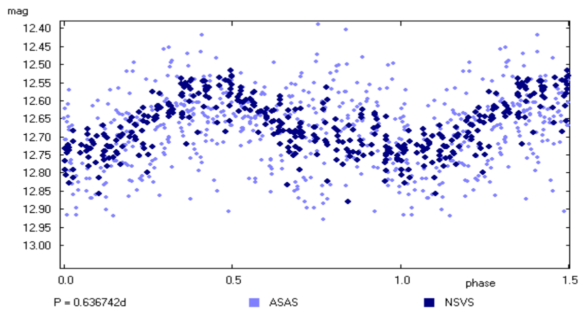
As a part of VS-COMPAS data-mining program, in the paper four new rotating BY Draconis variables are presented. The research result on these objects is submitted to the VSX catalog for the first time.



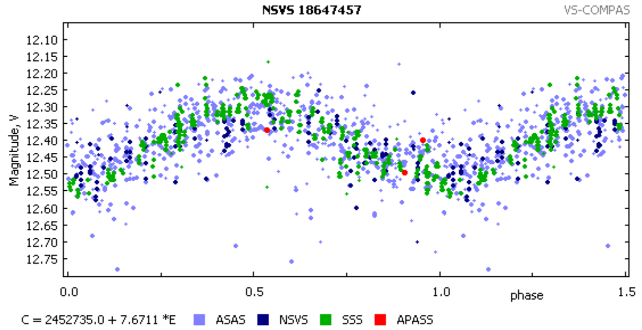
NSVS 352541 in Cassiopeia
by Alexandr Ditkovsky (VS-COMPAS)



NSVS 6762026 in Taurus
by Valery Tsehmeystrenko (VS-COMPAS)



VSX J095115.5+220811 in Leo
by Andrey Prokopovich, Ivan Adamin (VS-COMPAS), Sebastian Otero



NSVS 18711283 in Centaurus
by Alexandr Ditkovsky (VS-COMPAS)

Table 1. – The list of discovered BY Draconis variables, presented in the paper for the first time.

Object Designation	RA (J2000)	DEC (J2000)	Var. Type	Epoch, HJD	Period	Mag. Range
NSVS 352541	01 35 31.60	+69 09 55.3	BY	2451619.4	12.6	12.16 - 12.69 R1
NSVS 6762026	04 19 24.33	+29 45 58.6	BY	2454369.50	26.88	12.6 - 13.0 CV
VSX J095115.5+220811	09 51 15.52	+22 08 11.6	BY	2451631.436	0.636742	12.55 - 12.77 V
NSVS 18711283	12 24 43.31	- 35 52 27.0	BY	2452735.00	7.6711	12.25 - 12.55 V

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- Woźniak, P. R. *et al.*, 2004, *The Astronomical Journal*, 127, 2436

Four new BY Draconis variables found in the NSVS data

Ivan Adamin (1), **Alexandr Ditkovsky** (1), **Andrey Prokopovich** (1), **Valery Tsehmeystrenko** (1)

1 – The VS-COMPAS Project; http://vs-compas.belastro.net

Abstract: As a part of VS-COMPAS data-mining program, in the paper four new rotating BY Draconis variables are presented. The research result on these objects is submitted to the VSX catalog for the first time by the VS-COMPAS team members. Photometric data from publicly available surveys (primarily, from the NSVS and CRTS) was used as a source for light curves.

I. Introduction

The BY Draconis variables are rotating K and M dwarfs which exhibit low-amplitude photometric variability with typical periods of a few days. These variable stars have been of exceptional importance in the development of stellar surface activity understanding and provided the important source of data to connect theory of spotted star's surface with rotation.

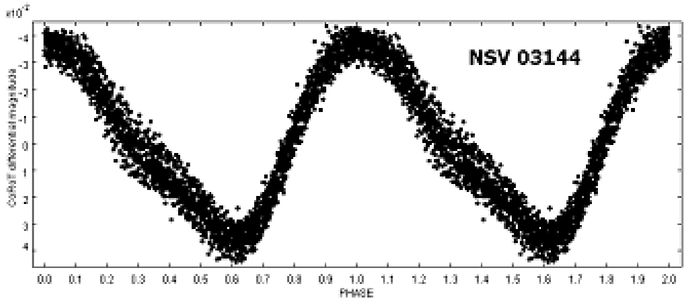


Figure 1. – Typical phase diagram of BY Draconis variable. The sample above is NSV 03144 (J.Greaves, 2010; PZP, 10, 8)

Resultant brightness fluctuations are generally less than 0.5 magnitudes. The first discovered BY Draconis variable is Ross 248 (HH Andromedae). Its variability was discovered by Gerald E. Kron in 1950. The variability of BY Draconis itself was discovered in 1966 and studied in detail by Chugainov in 1966 (Hall, 1994). The spectra of BY Dra variables are similar to RS CVn stars - another class of variable stars with active chromospheres. BY Draconis is a close binary consisting of a K6V dwarf and a M0V dwarf with an orbital period of 5.975 days and a mean separation of 0.05 AU.

Some of BY Draconis variables show flares, and are therefore UV Ceti stars (flare stars).

A model characterized by cooler, darker regions (starspots) on the surface of a rotating star appears to explain BY Draconis photometric variations (Kron, 1952; Torres and Ferraz Mello, 1973; Bopp and Evans, 1973; Vogt, 1975).

II. Candidates pre-selection and analysis

Candidates for analysis were selected by a custom piece of software created by I.Adamin. The software used the publicly available photometric databases, such as the Northern Sky Variability Survey (Woźniak et al., 2004), The Catalina Real-time Transient Survey (Drake et al., 2012), as a source of photometric measurements.

Then, the whole set of candidates was distributed among the VS-COMPAS Project team members for further analysis. During this phase of research there was a custom period search and data analysis software used, created by combined efforts of A.Prokopovich and I.Adamin.

For high-precision periodogram calculation the Lafler-Kinman (Lafler, Kinman, 1965) statistical algorithm implementation was used. The VizieR web services were broadly used for obtaining data on the objects.

III. The list of discovered objects

We report the discovery of 4 new variables of BY Draconis type. These are: VSX J095115.5+220811, NSVS 352541, NSVS 6762026, NSVS 18711283.

Below the results of this research are presented: a light curve for each object along with the name of its discoverer and light curve elements (cf. Table 1).

For *NSVS 352541* (J-K = 0.79) magnitudes are contaminated by two neighbors:

2MASS J01353005+6910236
(J-K = 0.93, V = 14.35)
2MASS J01352603+6909398
(J-K = 0.36, V = 14.0).

Thus, the range has been corrected for this object, taking into account photometric properties of its neighbors..

VSX J095115.5+220811 is particularly interesting for its short period, which is 0.636742 of a day. There are only 149 BY Draconis variables with period less than a day (out of 2633) in the VSX catalog at the moment of publication.

Gaia space observatory launched into space

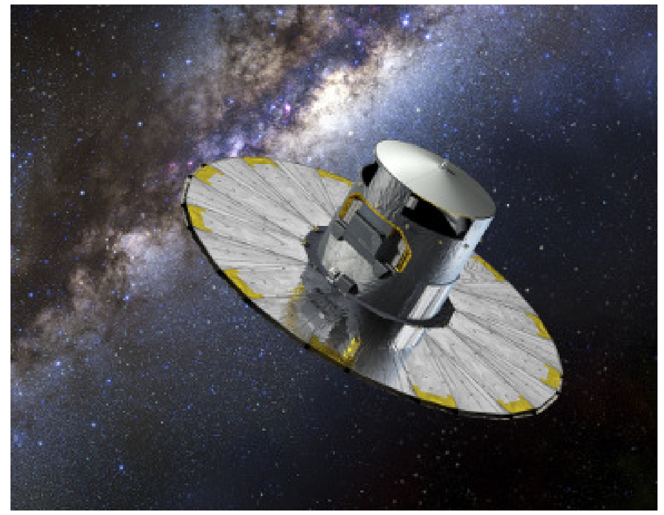
The five-year-long space trip of the telescope named Gaia started from Kourou in French Guiana on Thursday, December 19, 2013 at 9:12 UTC, where it was taken off on top of a Russian-built Soyuz-Fregat launch vehicle. The Gaia spacecraft is a successor to the Hipparcos satellite that was launched by Arianespace in 1989. The main purpose of the satellite telescope is to build the most detailed 3D map of the Milky Way galaxy.

The name 'GAIA' was originally derived as an acronym for Global Astrometric Interferometer for Astrophysics Gaia mission has been in development for 20 years, as a part of long-term ESA's space research program.

The 2,120 kg spacecraft will be placed into deep space in an orbit that will be of a Lissajous-type around the second Lagrange point (L2), at a distance of 1.5 million kilometers from Earth (0.01 AU).

Gaia will create a highly accurate three-dimensional map of stars throughout the Milky Way galaxy and map their motions. This will help to understand subsequent evolution of the Milky Way better. During its 5-years mission, Gaia will monitor each of its target stars about 70 times.

It is hoped that Gaia will give astronomers an extremely precise realistic picture of the Milky Way galaxy structure and evolution. Measuring the astrometric and kinematic properties of a star is necessary in order to understand the various stellar populations, especially the most distant ones.



An artist impression of Gaia. (AFP Photo / ESA / D. Durcos)

Eventually, a billion-star catalog of stars will be created. A billion of stars might be roughly one percent of the galaxy; however the previous research mission the Hipparcos catalogued a thousand times less celestial objects between 1989 and 1993.

Data gathered by the telescope will surely uncover tens of thousands of previously unseen objects. Besides new asteroids in our Solar System and exploding stars – supernovas – in other galaxies, scientists look forward to the opportunity of finding new planets around nearby stars.

The satellite is equipped with two key telescopes with 1.45 x 0.5m primary mirror each. Telescopes are projecting light from stars onto 1.0 x 0.5m focal plane array, which consists of 106 CCDs of 4500 x 1966 pixels each. To measure the radial velocity an integrated spectrometer observing the Doppler effect is used.

Launch of Gaia satellite on Soyuz rocket. Credit: ESA artist's concept by D. Ducros

Gaia will send back data for about eight hours every day at about 5 Mbit/s (about 200 TB of usable uncompressed data overall). ESA's two most sensitive ground stations, the 35 m diameter radio dishes in Cebreros, Spain, and New Norcia, Australia, will receive the data.

In October 2013 ESA had to postpone Gaia's original launch date, due to a precautionary replacement of two of Gaia's transponders, which are used to generate timing signals for the downlink of science data. Around 3 weeks is needed for Gaia to reach its designated orbit around the L2 point.

Interesting web resources to follow on the subject:

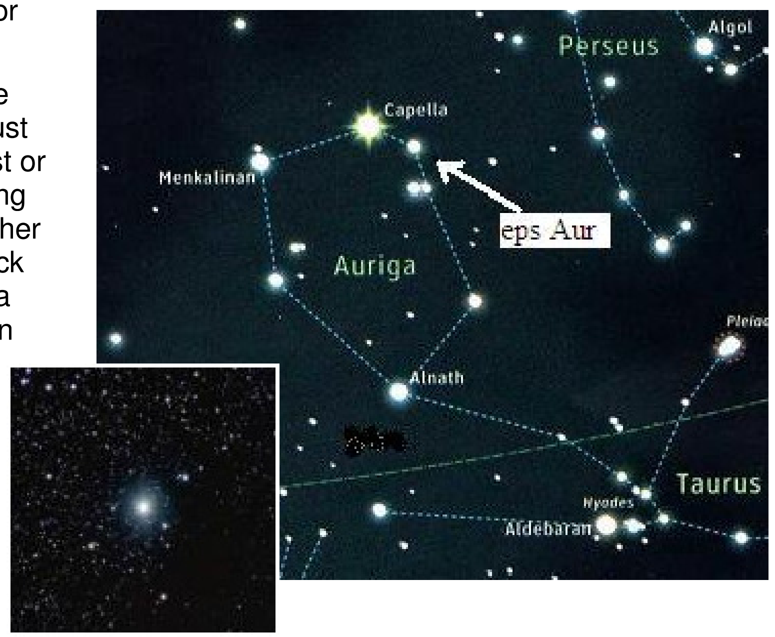
http://sci.esa.int/gaia/
http://www.spaceflight101.com/gaia-mission-and-orbit-design.html
http://www.russianspaceweb.com/gaia.html

Ivan Adamin

Epsilon Aurigae: a rare stellar eclipse

Epsilon Aurigae is the fifth brightest star in the northern constellation Auriga. It is the eclipsing binary star with the longest known orbital period, showing a single eclipse every 27.1 years. Eclipse duration is extremely long: it takes nearly 2 years for the companion to pass the star for an external observer's line of sight. For the last two centuries the nature of the eclipsing object was not reliably explained, until its long-awaited eclipse in 2009-2011.

Epsilon Aurigae (ε Aur, 7 Aur, SAO 39955, HD 31964) is located 3 degrees from Capella (alpha Aurigae) in a small triangular group of stars known as "The Kids". The main star of the epsilon Aurigae star system is a post-AGB hot-end yellow giant F0 II star with a mass of about 3 times our Sun (Hoard, 2010) and a diameter of ~135 times (Chadima, Harmanec, et al., 2011). The Epsilon Aurigae system is perhaps the most interesting eclipsing star system. It has puzzled astronomers for over 170 years.

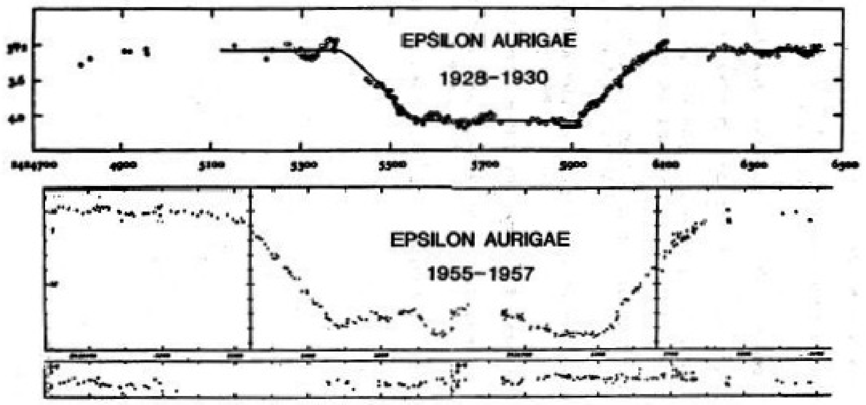


Many theories have been put forth as to what the eclipsing body is. A black hole or gigantic star are just a few. Most popular idea is that a large cloud of dust or gas orbiting the host star. But if that is true something massive must be embedded to hold the cloud together from the inside. The previous eclipse took place back in 1982-1984. The recent was in 2009-2011, when a new generation of telescopes had been prepared on this stellar enigma in an effort to unlock its mystery. This was only the seventh documented eclipse in history (2010, 1983, 1956, 1930, 1902, 1874 and 1847).

There is another interesting extremely long-period eclipsing binary star system known - 32 Cygni. Its brightness varies from 4.0 to 4.2 magnitudes every 1148 days, or 3.1 years. But the eclipse lasts only 11 days (Jancart, S. et al., 2005). Implying that to the epsilon Aurigae star system one would expect an eclipse to last less than 11 days, possibly even just hours. Instead, in fact, we observe a 2-years-long eclipse.

The discovery of epsilon Aurigae

The earliest mention of the variability of epsilon Aurigae was in 1821, by an amateur astronomer, High Minister Fritsch of Quedlinburg, Germany. Johann Fritsch was the first to note the variability, when the star was likely in the midst of a deep eclipse. This fact has been reflected in a written notice (Fritsch, 1824).



Epsilon Aurigae eclipse observations in 1928-1930 and 1955-1957

The German astronomers Argelander and Heis both began its observing once every few years around 1842-1843. The data showed that the star became significantly fainter around 1847. By September of 1848, epsilon Aurigae became significantly brighter again, reaching its near-normal brightness by the end of that year. Observers later in the 19th Century recorded another dimming event in 1874-1875, and another in 1901-1902. (*historical details are from the AAVSO article* http://www.aavso.org/vsots_epsaur *by Dr. Matthew Templeton*)

After this initial observation by Fritsch, several other observers obtained data on epsilon Aurigae, but until 1903 the dimming wasn't confirmed to occur every 27.1 years (Ludendorff, 1903). Later in 1912, H.N.Russell published the first analytic methods for binary star analysis, and in 1915 Harlow Shapley applied the method to

2MASS J21255780+4150086 (J-K= 0.77, V= 17.5, sep. 23"),
2MASS J21260015+4149259 (J-K= 0.56, V= 16.3, sep. 27"),
2MASS J21255733+4150122 (J-K= 0.93, V= 17.3, sep. 29"),
2MASS J21255585+4149505 (J-K= 0.96, V= 14.5, sep. 35"),
2MASS J21255877+4149089 (J-K= 0.61, V= 16.0, sep. 41"),
2MASS J21260005+4149088 (J-K= 0.74, V= 17.2, sep. 43"),
2MASS J21255800+4149051 (J-K= 0.70, V= 16.9, sep. 46").

Performed deblending of the light curve data allowed to find the real magnitude range. Taking in to consideration other properties of the star and its color index, it was classified as a Mira variable. The revision is submitted to the VSX.

Below there is a phased light curve along with a short summary for the NSVS 5907410 is presented. This is a typical light curve for Miras (cf. Figure 3).

This research has made use of the SIMBAD and VizieR databases operated at the Centre de Données Astronomiques (Strasbourg) in France; of the International Variable Star Index (AAVSO), and of the Two Micron All Sky Survey (2MASS). Period search and analysis software is created by Andrey Prokopovich and Ivan Adamin, members of the VS-COMPAS data mining project.

Appendix. Table1 provides a summary data about the target star.

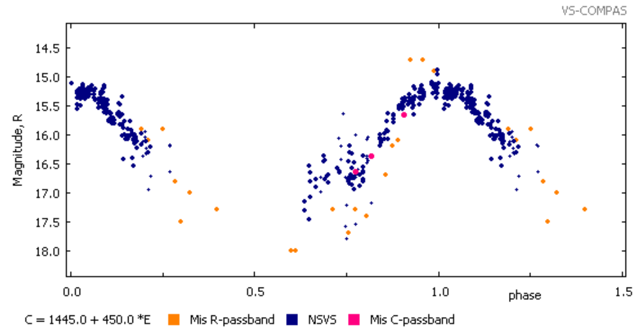


Figure 3. – *Generated phased light curve for NSVS 5907410. The period is 450 days. J-K = 1.98*

Table 1. – A short summary of the NSVS 5907410 object with updated elements.

NSVS 5907410 = MISAO V1119	
AAVSO UID	131755
Constellation	Cygnus
Other Names	2MASS J21255897+4149499 AKARI-IRC-V1 J2125589+414949 GSC2.3 N31P016928 UCAC4 660-096673 IRAS 21240+4136
Coordinates	21 25 58.98 +41 49 50.0 (J2000.0)
Mag. range	14.7 - 18.0 R
Epoch	23 Sep 1999 (HJD 2451445)
Period	450 days
Var. type	M

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NSVS 5907410 = MISAO V1119: a Mira variable confirmed

Siarhey Hadon

zenit76@tut.by; The VS-COMPAS Project

Abstract: Details of a Mira variable in the constellation of Cygnus are presented. The variability of the NSVS 5907410 source was detected in January of 2012 by Ivan Adamin, based on photometric data from the Northern Sky Variability Survey, as a part of data mining project, the VS-COMPAS. Lately, by the time the star's data was finally analyzed in 2013, the object was identified as the Mis V1119 classified as possible semi-regular. Thus, a revision with actual data was submitted.

Mira variables named after the star Mira (*o* Ceti), belong to a class of pulsating variable stars characterized by very red colors, pulsation periods mostly between 100 and 800 days, and amplitudes greater than one magnitude in infrared and 2.5 magnitude at visual wavelengths by definition.

In this paper a revision of MISAO V1119 variable is presented. Initially, the star discovered by Seiichi Yoshida, MISAO Project; Nobuo Ohkura, Okayama, Japan; and Ken-ichi Kadota, MISAO Project.

During the candidates selection process in the constellation of Cygnus as a part of data mining activity performed by VS-COMPAS Project team in January of 2012, the source identified as NSVS 5907410 was considered a variable. Later, by combining MISAO data with the photometry from the *Northern Sky Variability Survey* the variability class was determined as Mira.

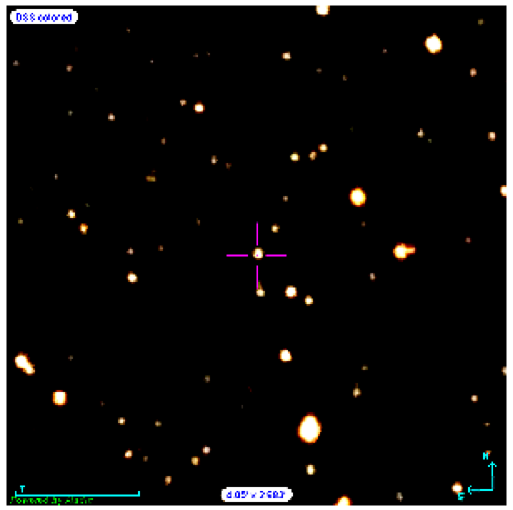


Figure 1. – *NSVS 5907410 and MISAO V1119 references to the same object*

The Northern Sky Variability Survey (Woźniak et al., 2004) has a moderate resolution, so there are cases when the source object for the photometric set is uncertain in the crowded fields. The pictures made by the MISAO clearly demonstrate that the object in the area referencing by NSVS 5907410 is the unique variable source among its neighbors.

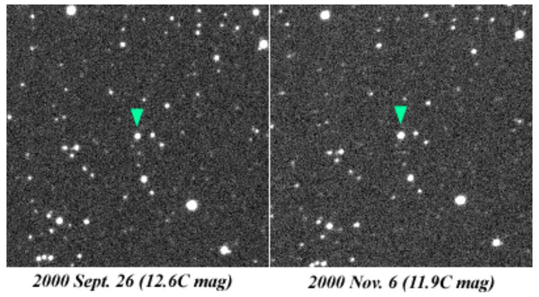


Figure 1a. – *MISAO comparison images proving the discovery of the variable star.*

Detailed analysis was made by Siarhey Hadon in November of 2013. Periodogram analysis of data for MISAO V1119 revealed a strong peak (cf. Figure 2) around a period value of 450 days. Photometric data points used were gathered by Nobuo Ohkura. This value has a good match with the blended NSVS data, for which a deblending was performed. Otherwise, the NSVS data is not enough to make a reliable decision about the proper period.

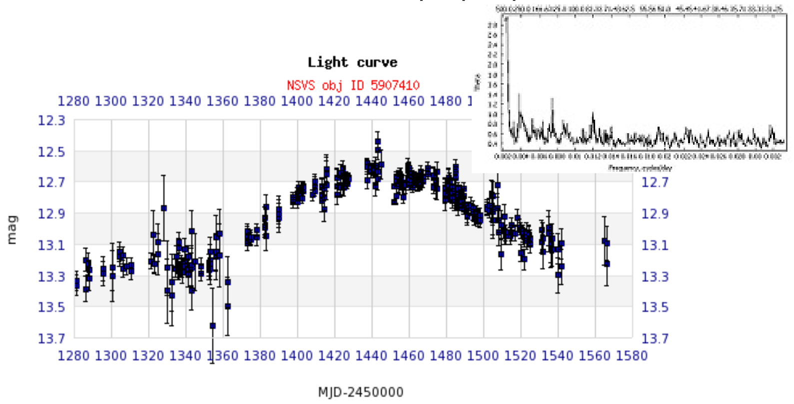


Figure 2. – *Photometry from the NSVS Survey has a good match with the periodogram for Misao V1119, based on data from the Misao Project*

The target star is in a crowded area, so the light curve data from the NSVS database was contaminated by the following non-variable neighbor stars:

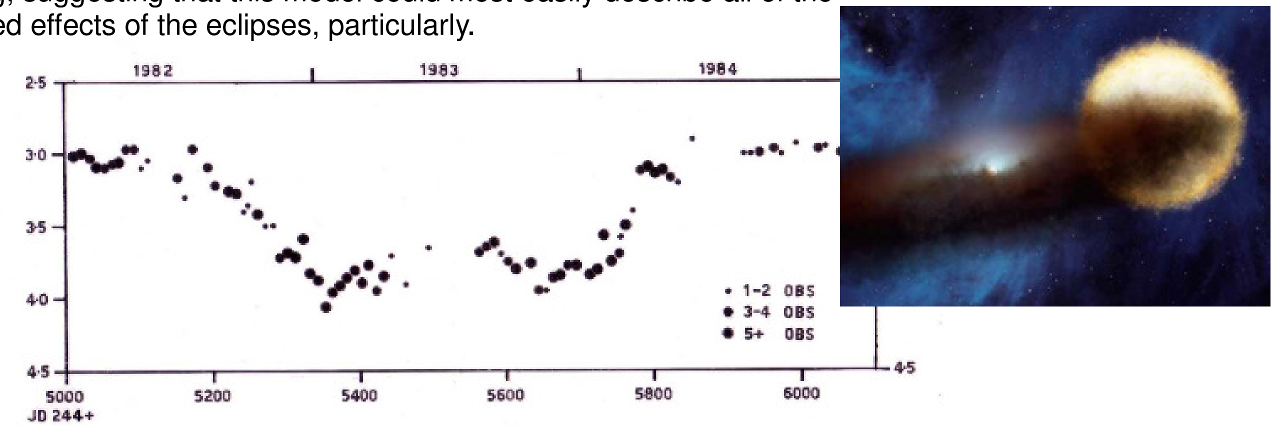
2MASS J21255941+4149369 (J-K= 0.81, V= 17.4, sep. 14"),

2MASS J21255855+4150082 (J-K= 0.64, V= 17.3, sep. 19"),

epsilon Aurigae with distressing results: the companion was as massive as the primary F supergiant star, but undetected in photometric and spectroscopic observations!

Untangling the mystery

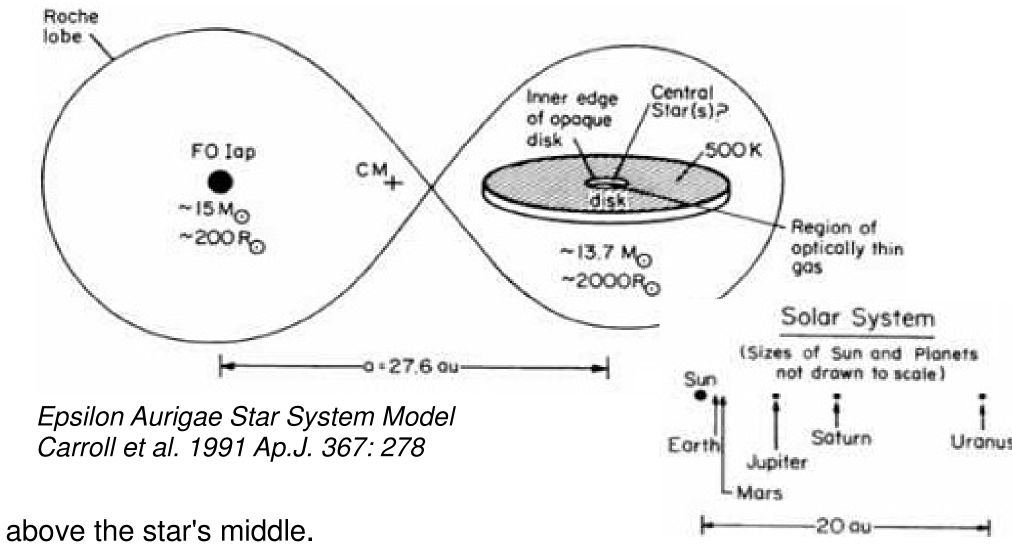
Several authors have attempted to explain the eclipse phenomenon, sometimes using the most exotic objects in the universe. Decade after decade, great names of 20th-century astrophysics tried to account for this behavior. During the 1928–30 eclipse, Dean B. McLaughlin and others detected spectroscopic Doppler shifts that indicated a vast rotating object crossing in front of the F supergiant. In 1937 an attempt to explain the phenomenon was made by Gerard Kuiper, Otto Struve, and Bengt Strömgren. They suggested the system was an eclipsing binary composed of an F2 primary star and an extremely cool star that they described as "semitransparent" orbiting the primary. In 1965 Su-Shu Huang suggested an edge-on thick disk as the eclipsing body. These theories could not explain the mid-eclipse re-brightening which was clearly noticeable during all known epsilon Aurigae eclipses. In 1971, Robert Wilson introduced a thin tilted disk with a central opening, suggesting that this model could most easily describe all of the observed effects of the eclipses, particularly.



Epsilon Aurigae eclipse observations in 1982-1984 with the mid-eclipse re-brightening clearly visible on the plot. Top right: artist's impression of epsilon Aurigae system. Credit: NASA / JPL-Caltech

Flat-bottomed eclipses of 2-years duration and their depth (2.9 to 3.8) optically suggest that the cold disk covers half the surface area of the F star (Huang 1965). A lot of information was collected during the eclipse of 1982 -1984. At the end of the campaign, in 1985 a workshop was held at the American Astronomical Society meeting in Tucson, Arizona, where tens of papers were presented. Despite that, the mystery still remained unresolved. Kopal presents the first ideas of a disk existing in the system in 1954. That was in remarkable agreement with current observational evidence. He proposed that the companion to the F-star is a flat, semi-transparent ring (disk) with a radius of ~ 6 AU and an opacity of 0.8. Kemp et al. (1986) analyzed polarimetry of the 1984 eclipse and argued that the disk is inclined 2-5 degrees from its orbital plane.

Later, Gary Henson, Kemp's PhD student, published all of the polarization data in his thesis and analyzed the out-of-eclipse variations. From Henson's work, there is evidence to support the F-star being a non-radial pulsator, thereby explaining the secondary variations in the light curve. According to this data, it was determined that the disk was tilted with respect to the orbit, and that the orbit crosses the F-star just above the star's middle. (*Source used: http://www.citizensky.org/book/export/html/1033*)

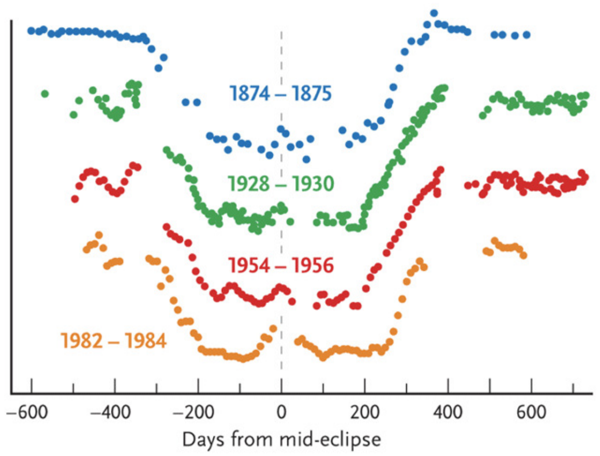


Epsilon Aurigae Star System Model Carroll et al. 1991 Ap.J. 367: 278

To hold the disk together, astronomers believe there must be at least one star at its center, yet none is visible. Modern theory estimates disk's diameter of ~8 AU, made of dusty material. Still a strange behavior: near the mid-point of the eclipse, the system appears to suddenly increase in brightness for a short time. Long period between epsilon Aurigae eclipses means each cycle taken up by new observers and technologies. The most recent eclipse began in autumn of 2009, so another campaign was planned. One of the remarkable advances since the 1983 eclipse of epsilon Aurigae is the significant progress in interferometric imaging. A good literature review on epsilon Aurigae before the 2009 eclipse subject can be found at http://www.citizensky.org/book/export/html/1349

The 2009-2011 eclipse: hardware progress made it all possible

The eclipse started in early September 2009. Having a year ahead, scientists had quite a bit of time to perform wide range of measurements and reconstruct the system with properties explaining the behavior. It is not an single night event, where the data have to be collected within minutes/hours, getting it lost otherwise. Seeing this eclipse in detail has only now become possible. For the first time, astronomers have directly observed the mysterious dark companion in a binary star system of epsilon Aurigae. Using an instrument developed at the University of Michigan, scientists have taken close-up pictures of Epsilon Aurigae during its eclipse.

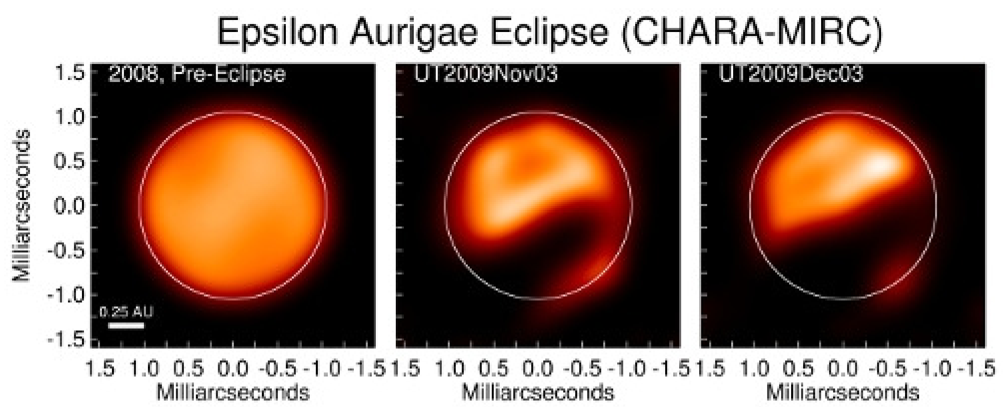


Eclipse durations measurements of epsilon Aurigae. Courtesy of CitizenSky.org.

A series of images obtained at the Center for High Angular Resolution interferometer with the Michigan Infrared beam Combiner (CHARA-MIRC) at Mt. Wilson show the progression of the 2009-2010 eclipse of epsilon Aurigae, the dark disk and its substructure (see image below).

John D. Monnier led the creation of the MIRC, which uses an "interferometry" approach to combine the light from six telescopes at the CHARA array* at Georgia State University. Such an amplification is equal to the light gathered through a device ~100 times larger than the Hubble Space Telescope.

The pre-eclipse observations in 2008(left) show the primary F-star as a nearly uniformly illuminated 2.27 milliarcsecond circle. The November 2009 observation (centre) shows the shadow of the disc (outlined in a white ellipse) around second contact and the December 2009 observations (right) show that nearly 50 percent of the stellar surface is obscured by the eclipsing object. Image: John D. Monnier, University of Michigan, (*Nature,* 8 April 2010). The image was obtained using the interferometric technique, an idea that incorporates computer control and laser connections among multiple telescopes to achieve signal equivalent to one giant telescope.



Images of epsilon Aurigae on the sub-milliarcsecond scale, during the ingress: 2009 (November and December). All images were acquired using CHARA-MIRC, the Michigan Infrared Combiner. Image Credit: John D. Monnier, University of Michigan

The ***CHARA Array*** (The Center for High Angular Resolution Astronomy) is an optical interferometer located at the Mount Wilson Observatory (California). The array is formed from six 1-meter telescopes arranged along three axes with a maximum separation length of 330 m, operated by the Georgia State University (GSU). It is among the most powerful facilities of its kind in the world for studying stars and stellar systems at resolutions not previously available. The light beams travel through vacuum tubes and are combined optically, with movable mirrors to keep the light in phase as the earth rotates. CHARA began scientific use in 2002. In the infrared, the array has an interferometric imaging resolution of 0.0005 arcseconds.

(Source: http://www.chara.gsu.edu/CHARA; Wikipedia)

HD 5980

HD 5980 (var. type: EA/GS/WR+SDOR) is the brightest star in the Small Magellanic Cloud and is located in *NGC 346*. It has three components, all amongst the most luminous stars known. In 1991, HD 5980 was observed to have changed spectral type and decreased in temperature after a slow increase in brightness. This is known eclipsing binary with possible eruptions occurring within an accretion disk around the companion. The variability period is 19.266 days.

Wolf-Rayet stars catalogs

- *The Seventh Catalogue of Galactic Wolf-Rayet stars*, by van der Hucht
  VizieR Catalog: http://cdsarc.u-strasbg.fr/viz-bin/Cat?III/215
- *Galactic Wolf-Rayet Catalog* - http://www.pacrowther.staff.shef.ac.uk/WRcat
- *A catalog of northern Wolf-Rayet Stars and the Central Stars of Planetary Nebulae*
  https://www.cfa.harvard.edu/~pberlind/atlas/htmls/wrcat.html
- *Wolf-Rayet Spectroscopic Survey*
  http://www.astrosurf.com/buil/survey/wrstars/wrstars.html

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Carina Nebula around the Wolf–Rayet star WR 22. Credit: ESO

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M1-67 (left, *Credit: ESO*) is the youngest wind-nebula around a Wolf-Rayet star in the constellation Sagittarius, called **WR124**, in our Galaxy. These Wolf-Rayet stars start their lives with dozens of times the mass of our Sun, but loose most of it through a powerful wind, which is ultimately responsible for the formation of the nebula. The image is based on FORS1 data obtained by the Paranal Science team with the VLT through 2 wide (B and V) and 3 narrow-band filters. (*Source Credit: ESO*).

All subtypes of WRs show a correlation between variability and luminosity similar to other supergiants. That is increasing variability with higher luminosity which corresponds to cooler WR stars: as they become hotter, they become more stable. The microvariability time scale is in the order of one day. The Wolf-Rayet progenitor stars and formation processes are not yet clearly understood. It appears that W-Rs can evolve from any sufficiently massive star. It is feasible that the most massive stars, ~120 solar masses, may lose their original envelope during H burning, evolving directly from Of to W-R stages (Maeder, 1989). Eventually the WR star will run out of fusible material, ending its life as an early WC (WO) star in a type Ib supernova.

About half of WR stars are noticeably variable, with WN8 stars being considered to have the highest level of variability, with typical ranges of 0.1-0.2 mag. There are 32 WR stars listed in the GCVS4. The question of pulsation in WR stars is not settled though. WR stars are among the targets for ultra-precise photometry by the MOST satellite. Clear variability was measured for *EZ CMa* (P=3.763 days), *V919 Sco* (P~2 days), *V444 Cyg* (P=4.212424), *DI Cru* (P=0.3319).

Notable Wolf-Rayet stars

The most massive star and probably most luminous star currently known, ***R136a1***, is also a Wolf–Rayet star of the WNh type indicating it has only just started to evolve away from the main sequence. It is a member of R136, a super star cluster near the center of the 30 Doradus complex (also known as the Tarantula Nebula), in the Large Magellanic Cloud. The star is estimated to be of 265 solar masses and among the most luminous star known at 8.7 million times the luminosity of the Sun. (Crowther, 2010).

Gamma 2 Velorum

No WR star is so easily found as the bright naked-eye (1.81m) Gamma ^{2} Velorum in the southern constellation Vela, a famous visual multiple with a brilliant Wolf-Rayet primary. Gamma 2 Velorum is not only the closest Wolf-Rayet star but one of the brightest stars in the sky. At a distance of about 1,000 light-years away, it is part of a six-member star system. The primary star is a spectroscopic binary, the unseen component being a giant type O7 star. Though it's currently nine times our sun's mass, it has lost a considerable amount of its matter. Most likely, it started off with over 35 times the mass of the sun!

Theta Muscae

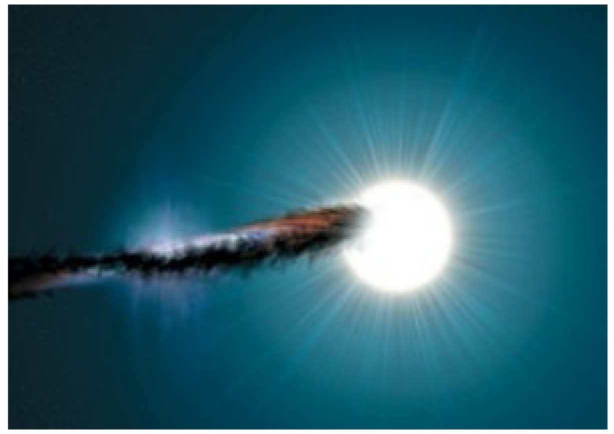
The second brightest is Theta Muscae (apparent magnitude of 5.66). It is a remote triple star system, the primary component of which is a carbon-sequence Wolf–Rayet star. The triple star is composed of two parts: a spectroscopic binary system of the Wolf–Rayet star and an O-type main sequence star that orbit each other every 19 days, and a blue supergiant. All three are highly luminous: combined, they are over a million times brighter than the Sun.

Eta Carinae

When Eta Carinae was first catalogued in 1677 by Edmond Halley, it was of the 4th magnitude, but by 1730, observers noticed it had brightened considerably and was, at that point, one of the brightest stars in Carina. The system contains at least two stars, of which the primary is a luminous blue variable (LBV) that initially had around 150 solar masses, of which it has lost at least 30. This stellar system is currently one of the most massive that can be studied in great detail. In 2005 it was proved to be a binary system.

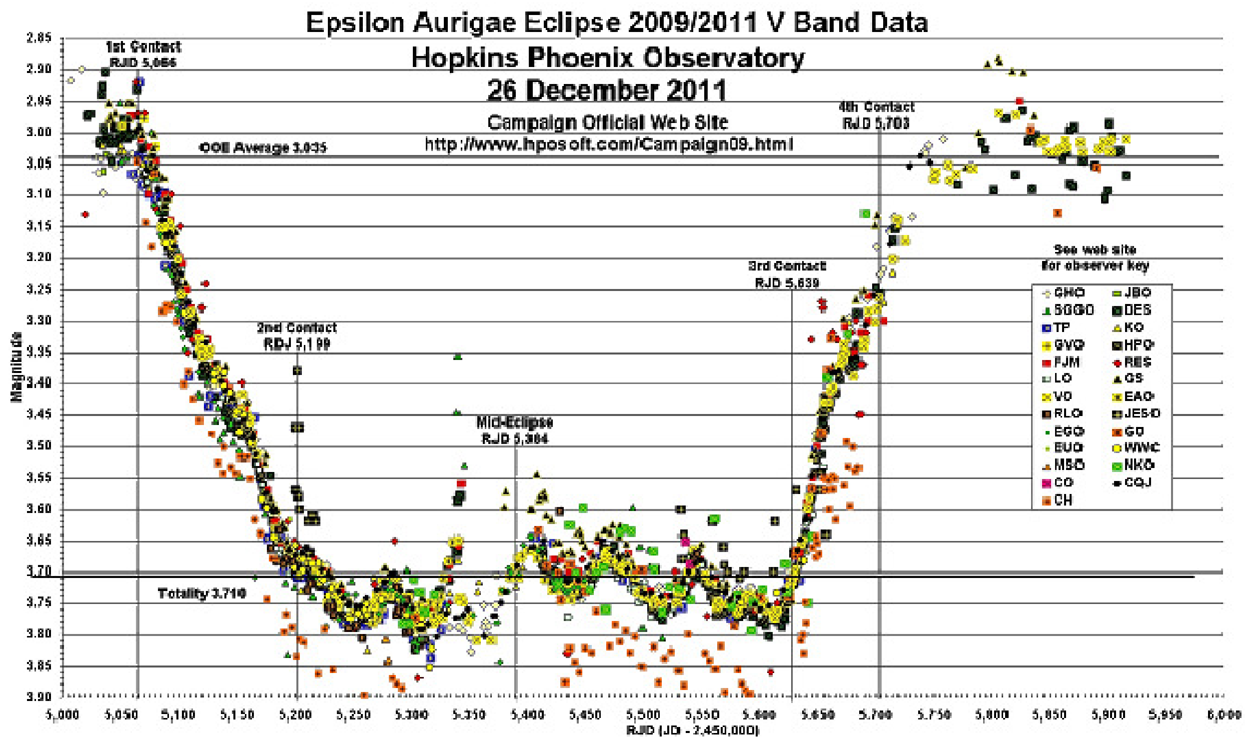
AB7 nebula.(Credit: ESO)

This data was also confirmed with the direct observation of the current eclipse from an international team lead by Brian Kloppenborg at the University of Denver. The new images show that this is the case: a geometrically thin, dark, dense, but partially transparent cloud can be seen passing in front of epsilon Aurigae. The images taken over a month clearly show the black silhouette of the disc beginning to move across the surface of the primary star. The size of the disc was measured at about 2.4 billion kilometers across, which is almost two times larger of the orbit of Jupiter. Though disk's mass was estimated to be ~ 0.1 that of Earth. It is enough for the disc to hide the brighter and hotter B-type star of 5.9 solar masses inside. The disc effectively blocks most of its light from an outermost observer.



Artist's concept of epsilon Aurigae system. Credit: Casey Reed, S&T

In May of 2006, Dr Robert Stencel of the University of Denver, who has been studying epsilon Aurigae since the 1980s, along with amateur astronomer Jeff Hopkins created a website to cover all the observations and analysis of the 2009-2011 eclipse. The website is called "*International Epsilon Aurigae Campaign 2009*". The page is alive, and now it provides a wealth of data gathered by observers all over the world, as long as published papers list. Over a thousand amateur observers sent their measurements in order to contribute to the campaign. As the result, a combined light curves in different bands were published covering all eclipse's phases. The website is parked at *http://www.hposoft.com/Campaign09.html* Below is the light curve covering the visual band measurements of epsilon Aurigae eclipse in 2009-2011.



The whole story is a really good example of how combining of efforts of many scientists and amateurs can lead to a true discovery. Though the research is not over, the concept of dusty disk around of the companion star is considered proven after a more than 170-years way...

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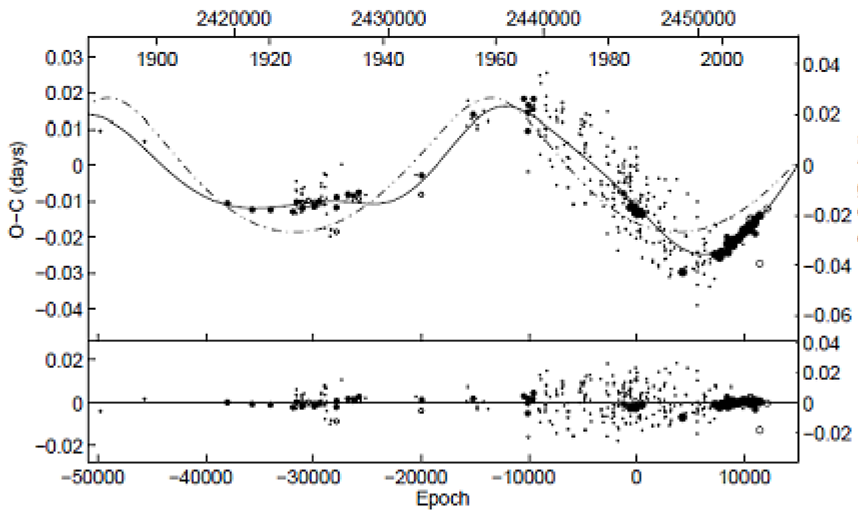
O-C diagrams basics

Most variable stars change its brightness over a cycle. O-C diagrams compare the actual timing of an event (e.g. the mid-point of an eclipse or a pulsation cycle peak) to the moment we expect this event is occurred in a case of constant periodicity. These period variations are usually delicate. By building Observed-minus-Calculated (O-C) diagrams one can measure very subtle changes in the period happening with the star.

O-C diagrams is a powerful diagnostic tool in the natural sciences. Basic period analysis consists of finding a reliable ephemeris of the main periodic variation and modelling of the first order effects. The basic mechanisms of the periodic or nearly periodic stellar variability are the rotation of an anisotropically radiating star, the orbital motions of components in stellar systems, and pulsations or oscillations of various kinds (Mikulášek et al., 2011).

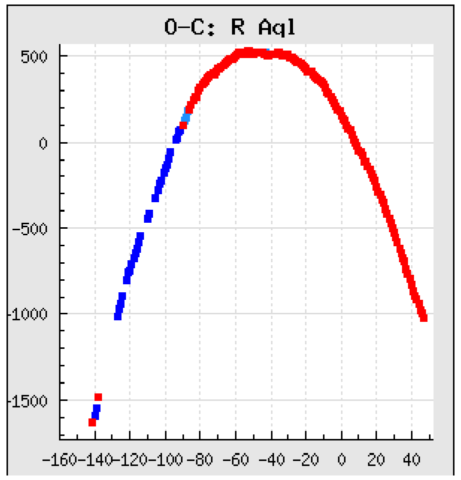
The O-C diagram is a plot showing the observed times of maximum light (O) minus those calculated according to an adopted ephemeris (C) as a function of time. The horizontal axis of the an O-C diagram most often represent time, usually expressed in days. Scientists principally use the Julian Date (JD) of the observation. It can also be cycles or phase. The vertical axis is the "O-C" part which gives the diagram its name and its interpretive power. For each observed event one takes the observed time of the event (that's the "O" part) and subtracts the time predicted from the existing data or model of the star. The difference, Observed minus Calculated or "O - C", is plotted on the vertical axis of the graph. The pattern that shows up in the O - C diagram can tell if your predictions (or model) are valid.

For a star with no measurable change in the period (or in a case of constant period), points on the O-C diagram will scatter about a straight horizontal straight line across the graph. The size of the scatter is an indication of the accuracy of the observed times of maximum. The O-C method, basically, assumes the use of a stable and accurate clock. The credibility of obtained astrophysical information strictly depends on the reliability of observation times and their uncertainties. If the period of the star is changing at a slow constant rate ($P(t) = P_0 + Bt$, where B is a small), then a good approximation of the O-C diagram can be represented by a parabola.



The O–C diagram of WZ And (upper part), where the solid line represents the theoretical LITE variation caused by a 3rd body and the O-C residuals obtained after the subtraction of LITE (lower part). For details, please refer to (Zasche, Liakos et al., 2009)

Note that in order to interpret an O-C diagram correctly, you have to know a number of cycles have elapsed between observed extremums. This is not always the case, since there may be large gaps between observations. Other problem is when the period has been changed significantly between observations.



The longer the time interval (in cycles) over which the data have been collected, the higher will be the resulting accuracy of the solution. If your period is slightly off, the discrepancy will accumulate as times goes on. In that case, the O-C diagram will look like an inclined straight line.

If the O-C diagram turns out to be curved, the period of the system is changing slowly. Imagine the middle horizontal line of the graph as a zero-level. Then positive is up and negative is down. A curve leading downwards indicates a shortening period: the events are happening earlier and earlier than predicted. If it curves upward, the events are happening later and later than expected, so the period is increasing.

Left: O-C diagram for R Aql
(by Thomas Karlsson, http://var.astronet.se)

Wolf-Rayet stars: extremely hot, luminous and massive

Wolf-Rayet stars are named after Charles Wolf (1827 - 1918) and George Rayet (1839 - 1906), French astronomers who discovered these unusual stars at the Paris Observatory in 1867, using the 40-cm Foucault telescope. 150 years later, we know of only 580 in the Milky Way galaxy, and a few hundred in the surrounding galaxies, so they are rare. Wolf-Rayet are evolved, massive, extremely hot (up to ~50,000 K) and very luminous stars, 10^5 to 10^6 times brighter that of the Sun.

The Wolf-Rayet stars represent an advanced stage of massive stars evolution and are characterized by an extraordinary spectrum which is dominated by emission lines of highly ionized elements, with lack of hydrogen. They are thought to mostly be dying supergiants with their hydrogen layers blown away by stellar winds. These stars are likely to end their lives spectacularly as either a Type Ib or Type Ic supernova explosion. Wolf-Rayets are massive stars. Masses can generally only be estimated from binary systems, which are commonly WR+O systems. The spectral types of the O companions show no correlation with W-R subtype (Massey, 1982).

Most of early studies of WR stars were confined to the WR+O binaries. By simply measuring the velocities of both components in a WR+O system, the minimum masses and the mass ratio of the two stars can be find. Known orbit inclination allows to calculate the mass of the WR star directly (Massey, 1982). Typical masses are around 16 to 18 M_0, but the range is very great: from 5 M_0 to 48 M_0 or, in one case (WR 22, HD 92740), 77 M_0. Masses of the O star in WR+O binary systems range from 14 to 57 M_0, with a mean of 33 M_0 (Cherepashchuk, 1992).

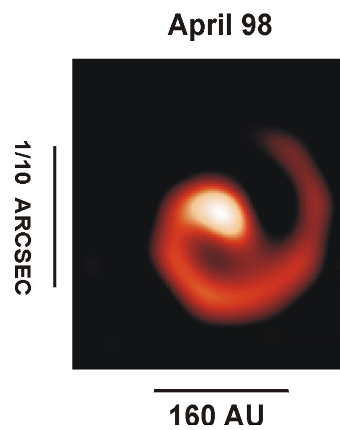
Overall pattern of the WR distribution within our galaxy suggests spiral arms: the stars are strongly concentrated to the inner edges of the HI and OB spiral features in Cygnus and Carina (Lindsey, 1968). Moreover, WR population varies qualitatively within the galactic plane. (van der Hucht et al., 1988).

NGC 2359** (Thor's Helmet) - the nebula which is located about 15,000 light-years away in the constellation Canis Major. Known as a Wolf-Rayet star, the central star is an extremely hot giant thought to be in a brief, pre-supernova stage of evolution. The nebula is about 30 light-years across. The central star is known as **WR 7** or **HD 56925.

***Image Credit:** Steve Mazlin, Jack Harvey, Rick Gilbert, and Daniel Verschatse (APOD; June 5, 2010)*

The classification of WR stars assumes dividing into subclasses according to relative strength of nitrogen and carbon emission lines in their spectra (Smith & Maeder, 1988). Two main subclasses are: type **WN,** where the ions of helium and nitrogen are dominating, and WC type exhibiting strong lines of carbon (Crowther, 2007). Rare WO stars contains strong Oxygen lines in their spectra.

Examples of Wolf-Rayet stars occurring in clusters include two in the ~3 million year old NGC 6231 in Scorpius, one in NGC 2359 in Canis Major (widely known as Thor's Helmet), one (HD 148937) associated with NGC 6164-65 in Norma, and another (HD 192163) associated with NGC 6888 in Cygnus (Johnson & Hogg, 1965) . Studies of WR stars in open clusters and associations are important as there is a chance to get a reliable information regarding their absolute magnitudes and intrinsic colours. For detailed analysis of WR stars in open clusters, see Lundstrom & Stenholm (1984).



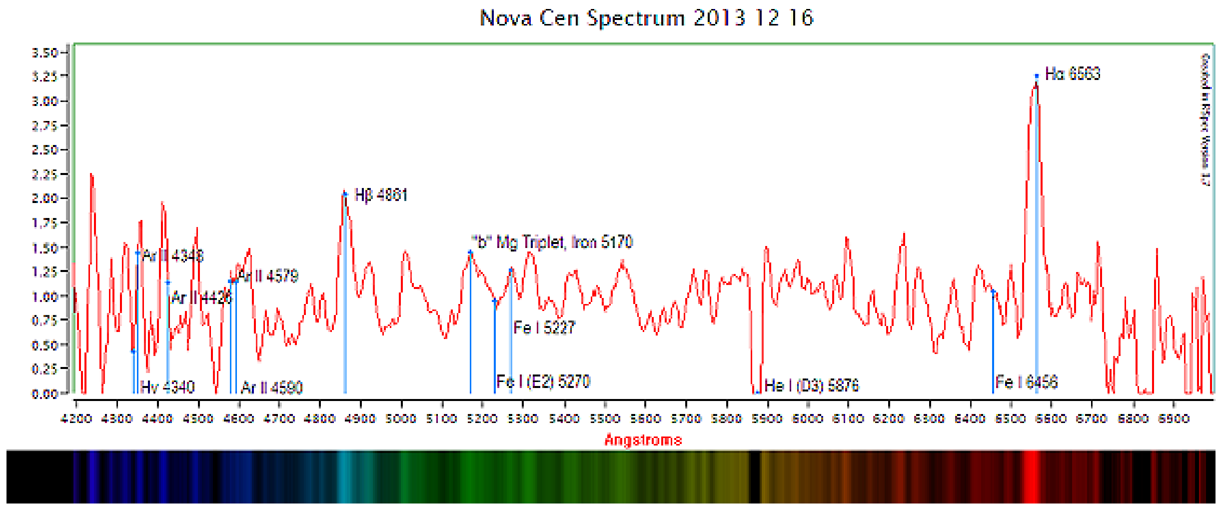
Many different proposals on scenarios for the formation of Wolf-Rayet stars were made in the literature (Maeder, 1982, 1983; Langer, 1988). In addition to the mentioned papers, there is a good resource containing details on WR models: PoWR (The Potsdam Wolf-Rayet Models), available online at the following address: http://www.astro.physik.uni-potsdam.de/~wrh/PoWR

WR 104 (left) is a Wolf-Rayet star discovered in 1998, located 8,000 light years from Earth. It is a binary star with a class OB companion. The stars have an orbital period of 220 days and the interaction between their stellar winds produce a spiral outflow pattern over 200 AU long (Tuthhill, 2009).

Left: The Twisted Tale of Wolf-Rayet 104 at 2.27 microns. First of the Pinwheel Nebulae.
Photo Credit: U.C. Berkeley Space Sciences Laboratory/W.M. Keck Observatory
Online: http://www.physics.usyd.edu.au/~gekko/wr104.html

Spectra of the Nova Centauri 2013 shows dominating peaks of Ha and Hb lines, which means the outburst is a classical nova. Below a spectra of the Nova taken on Dec 16 by Jerome Jooste is shown. A spectra taken by Malcolm Locke (New Zealand) and Rob Kaufman (Australia) also detected the strong and broad hydrogen emission lines typical of novae early in outburst,when a white dwarf star accreting matter from a binary companion until a new round of nuclear fusion occurs.

There is no reliable distance measurement for Nova Cen 2013 published yet.



Jerome Jooste has been taking spectra of the Nova; the example is taken on December 16. Credit: Jerome Jooste (2013)

Novae are distant cousins to Type Ia supernovae. In novae, the surface of the white dwarf produces a powerful explosion, but the white dwarf itself survives. In a Type Ia supernovae, the white dwarf accumulates just enough mass from its binary partner to be pushed above the Chandrasekhar limit of about 1.4 solar masses. This triggers a massive thermonuclear explosion that blows the entire white dwarf to smithereens. In the last 112 years, 48 novas have brightened into naked-eye view.

There are 10 known galactic recurrent novae (Schaefer, Bradley E., 2009) The recurrent nova typically brightens by about 8.6 magnitude, whereas a classic nova brightens by more than 12 magnitude. Below some good known exmaples of recurrent novae are listed to observe fairly easy.

Galactic recurrent novae

Object Designation	Short Name	Mag. Range	Days to drop 3 mag from peak	Eruption years
RS Ophiuchi	RS Oph	4.8–11	62	2011, 1967, 1944, 1920, 1902
T Coronae Borealis	T CrB	2.5–10.8	14	2006, 1985, 1967, 1958, 1933, 1898
T Pyxidis	T Pyx	6.4–15.5	6	1946, 1866
U Scorpii	U Sco	7.5–17.6	2.6	2010, 1999, 1987, 1979, 1936, 1917, 1906, 1863

Resources for further reading:

http://www.cbat.eps.harvard.edu/unconf/followups/J13544700-5909080.html
http://www.aavso.org/aavso-alert-notice-492
http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/16689
http://southern-sky-observations.blogspot.com/2013/12/nova-centauri-2013.html
http://phys.org/news/2013-12-naked-eye-nova-erupts-centaurus.html
http://www.aavso.org/vsx/index.php?view=detail.top&oid=358927
http://www.cbat.eps.harvard.edu/nova_list.html

Schaefer, B. E., 2010; Astrophys. J., Suppl. Ser., 187, 275
VizieR Catalog: http://cdsarc.u-strasbg.fr/viz-bin/Cat?J/ApJS/187/275

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The appearance of an O-C diagram is strongly dependent on the ephemeris formula used to construct it. Traditional analysis ways of an O-C diagram use basic method listed below (Batten, 1973; Tsessevich, 1973).

1) a linear approximation, where the time of the primary minimum is given by a linear relation:

$$MinI = t_0 + P_{orb} \times E$$

2) a quadratic least square fitting, which uses the average period value over the elapsed time interval ($\bar{P}$):

$$(O-C) = 1/2(dP_{orb}/dt)\bar{P}E^2$$

3) which is sometimes combined with a sinusoidal periodic variation.

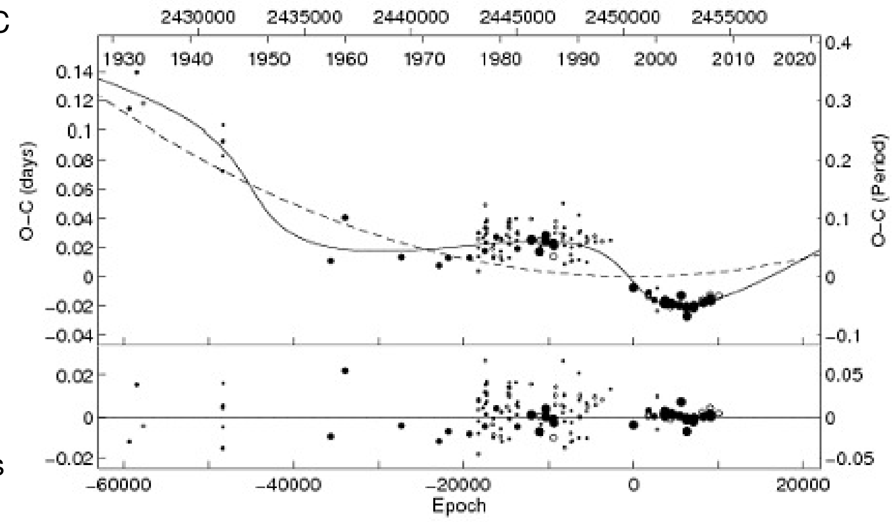
$$MinI = t_0+PE+1/2(dP/dt)PE^2+\alpha \sin(2\pi E/P_*+\phi)$$

There were three new ways of O-C diagram treatment proposed in the mid-90s:

- the higher order polynomial method (HOP), or the first continuous method (Kalimeris et al., 1994);
- the state-space statistical model (SSM), proposed by (Koen, 1996);
- the second continuous method (Jetsu et al., 1997).

For methods detail, please refer to the following paper: "The (O-C) Diagrams of Eclipsing Binaries: Traditional and New Ways of Treatment" (Rovithis-Livaniou, 2001).

To get even more information on methods for O-C diagrams and errors accounting, please follow the publication: "The O-C Diagram: Basic Procedures" (Sterken, 2005).



The O-C diagram of FZ Ori (upper part), where the solid line represents the theoretical LITE variation caused by a 3rd body and the O-C residuals obtained after the subtraction of LITE (lower part). For details, please refer to (Zasche, Liakos et al., 2009)

Useful links and web sources:

O-C diagrams for a selection of Mira stars, with the observations data table behind it (compiled by Thomas Karlsson).

http://var.astronet.se/mirainfooc.php
http://var.astronet.se/mirainfoper.php

An Atlas of O-C diagrams of Eclipsing Binary
http://www.as.up.krakow.pl/o-c/

Eclipsing Binaries Minima Database
http://www.oa.uj.edu.pl/ktt/krttk_dn.html

Kepler Eclipsing Binary Catalog
http://keplerebs.villanova.edu/

3400 O-C files of Eclipsing Binaries
(compiled by Bob Nelson)

http://www.aavso.org/bob-nelsons-o-c-files

Photoelectric Minima of some ***Eclipsing Binary Stars***
(compiled by Tom Krajci)

http://www.konkoly.hu/cgi-bin/IBVS?5690

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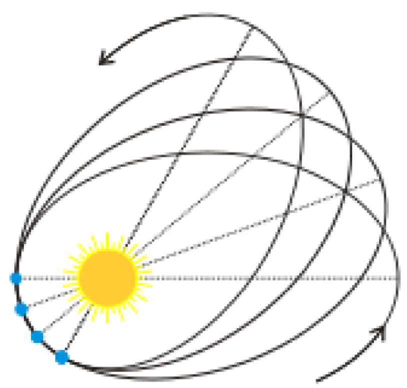
Eclipsing binary systems with eccentric orbits

Eccentric eclipsing binaries are a subgroup of detached binary stars that have provided new and important information for the study of internal stellar structure. Eccentric systems display the phenomenon of Apsidal motion. In particular, apsidal motions in this type of binary systems has proven to be highly rewarding during the past decades, allowing to get valuable astrophysics parameters of the binary system.

Currently there are more than a hundred eccentric eclipsing systems known. Many of them still require extensive observations for creation of reliable astrophysical models of their systems. Below one can read a short overview of this kind of systems and their examples

The apsidal motion effect

The study of apsidal motion effect in detached eclipsing binary systems with eccentric orbits (EEB) is an important source of information on the stellar internal structure as well as for the possibility of verification of the theory of General Relativity (Claret & Gimenez 1993; Claret 1997). It is the rotation of the line of apses of the orbit of an eccentric or elliptical two body system. The rate of motion of the apsis is dependent on the internal structure of each component. Determination of the characteristics of a binary thus provides an observational test of the theory of stellar structure and evolution.



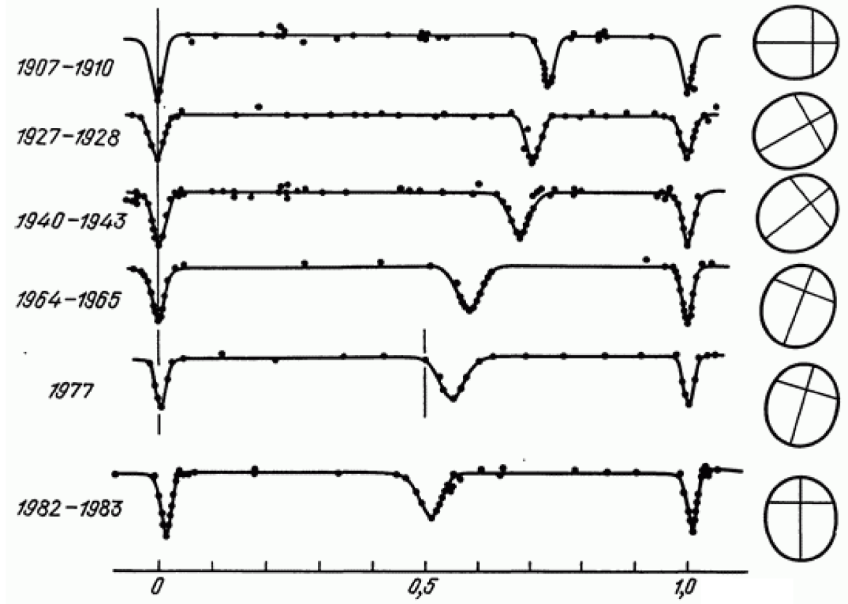


Fig.1. *The light curve evolution of RU Mon between 1907 and 1983, due to the apsidal motion effect (right). Schematic model of the line of apsides rotation (top).*

The first theoretical explanation of apsidal motion (the precession of an eccentric orbit in its own plane) extends back to the beginning of the 20th century. The history of apsidal motion studies based on observations of times of minima of eclipsing binary stars is long and interesting. It began with the recognition by Dunér (1892) that there were two separate types of minima of Y Cyg with significantly different periods, and he correctly atrributed this effect to a rotating line of apsides. This massive binary is one of the best-known cases of apsidal motion among eclipsing binaries.

The initial idea to measure the motion of the periastron of binary stars in order to have some insight into their internal structure was given by Russell (1928). In eccentric binaries, the behavior of the orbit is influenced by the distortion of the components. This is a function of the internal density concentration as well as the mass ratio and the separation of the components. Stellar distortion, or deviation from the point-like behavior, is responsible for the secular movement of the periastron and its observational measurement should obviously lead to an empirical measurement of the level of the density concentration. A fairly good historic introduction can be found in (Gimenez, 2006).

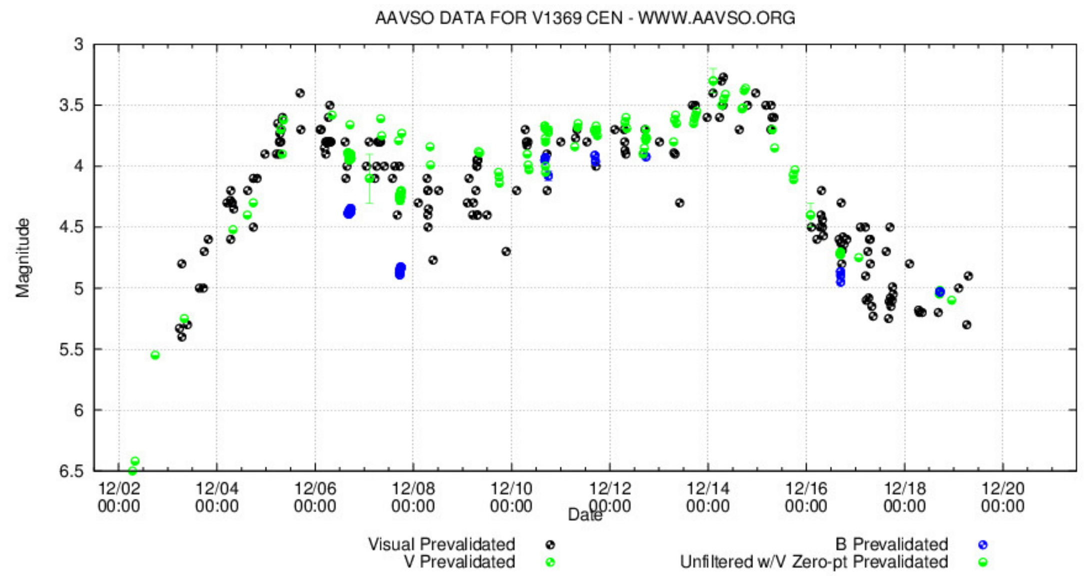
From the observational point of view, the study of this effect requires a more or less continuous monitoring of times of minimum light of the candidate systems. The necessarily long time basis of the observations requires a careful preparation of programs and targets.

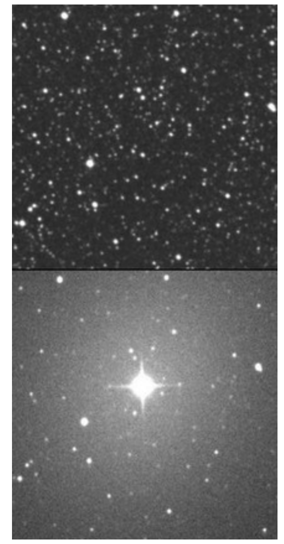
This means that a large amount of observing time is generally needed which is not available at large instruments. Since only accurate timings of relatively deep eclipses are needed, a moderate or even small telescopes equipped with a photoelectric photometer or a CCD camera can be perfectly suited to this kind of project.

V1369 Cen : a naked-eye nova erupts in Centaurus!

On Monday, December 02, amateur astronomer John Seach from Chatsworth islands of New South Wales (Australia) reported the discovery of a new star (5.5m) in the constellation Centaurus, not far from Beta Centauri. A nova is a massive nuclear explosion on a dying star. These stars - white dwarfs - are the final evolutionary stage of Sun-like stars. This Nova is the second naked-eye nova burst in a couple of months! And it's even brighter than Nova Delphini 2013.

About 40 nova explosions erupt in the Milky Way each year, but only about a quarter of them are actually observed. Once a nova is observed, a light curve can be compiled, and based on the curve it is classified as either a fast, slow, very slow, or recurrent nova. The brightest nova of the latest decades was Nova Cygni 1975, which reached mag 2.0. Recent Nova Delphini appeared in August 2013 reached mag 4.3. The Nova in Centaurus quickly reached 3.2m on Dec 14th, breaking the top 20 brightest new stars of all time.

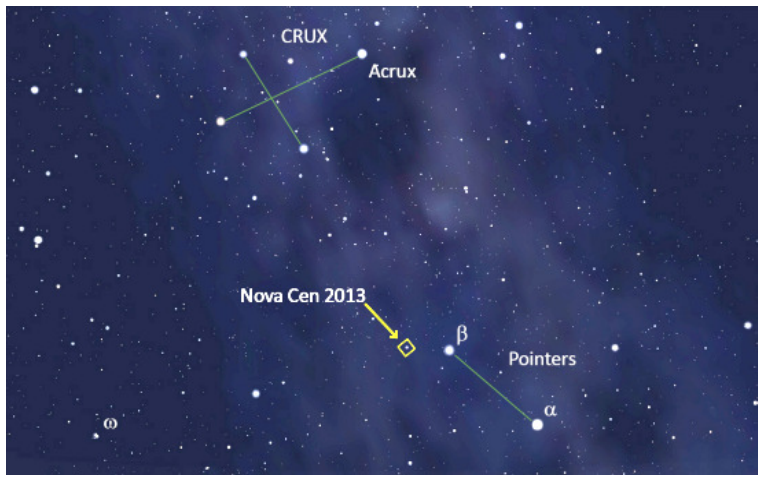




Nova Centauri 2013 photometric observations between 12/3/2013 and 12/19/2013.
The chart is generated by the AAVSO web service. Comparison images (right) are based on data collected with the Danish 1.54-m telescope at the ESO La Silla Observatory

On December, 03 the discovery was confirmed by other astronomers, and the AAVSO has issued a notice about the nova burst with the number 492. The nova has been assigned the designation V1369 Cen.

Brian Skiff (Lowell Observatory, USA) has suggested that the possible progenitor star is 3UC 062-280459 (J2000.0 coordinates 13 54 45.35 -59 09 04.1), and notes that there is an XMM-Newton x-ray source 2″ away. A recent (2010) paper by Richard Strope, Bradley Schaefer and Arne Henden presents a modern classification system for novae, based solely on the appearance of the light curves – "Catalog of 93 Nova Light Curves: Classification and Properties" can be downloaded from arXiv.



***Nova Centauri 2013** (RA: 13h 54m 45s DEC: -59d 09m 04s)*
***Discovery date**: 2013 December 02.692 UT*

The object is very probably identical with a ~ 15 mag star USNO-B1.0 0308-0442031 = 2MASS 13544534-5909040 = UCAC4 155-128029, which was identified as a probable progenitor of the possible nova. If the identification is correct, the estimated amplitude of the outburst is ~ 10 mag, which is consistent with the outburst of a classical nova.

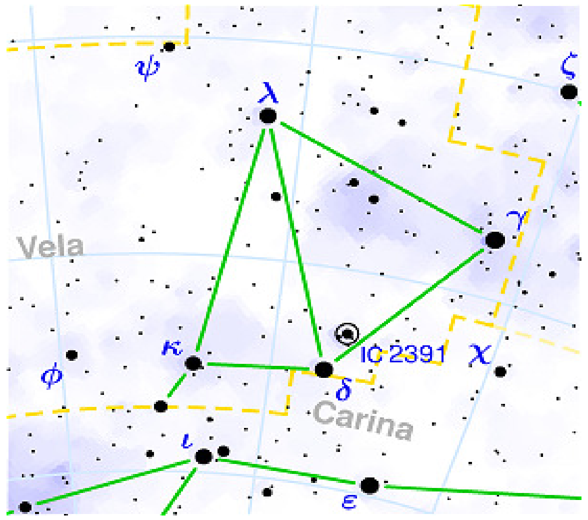
This should not be confused with a *supernova*, the last of which observed in our galaxy was Kepler's Supernova in 1604, just before the advent of the telescope in modern astronomy.

Soon after the discovery the nature of the burst was confirmed by spectroscopic observations.

The nearby eclipsing stellar system δ Velorum

Delta Velorum (δ Vel) is the second brightest star (m_v = 1.96) in the southern constellation Vela, near the border with Carina. The system is known due to its multiplicity and includes at least three identified components. Delta Velorum is among our closest stellar neighbors.

The multiple stellar system *δ Vel* (HD 74956, HIP 41913, GJ 321.3, GJ 9278) contains one of the nearest and brightest eclipsing binaries. The binarity of δ Vel was discovered by S. I. Bailey in 1894 from Arequipa, Peru (and independently by Innes 1895). It has already been known as a quadruple system for many years as IDS 08419-5420 (Jeffers et al., 1963) The system contains two pairs which are located apart at an angular separation of 69 arcsec. The bright close pair AB is separated by 2". The distant satellite binary system CD has its components of 11m and 13m splitted by 6".

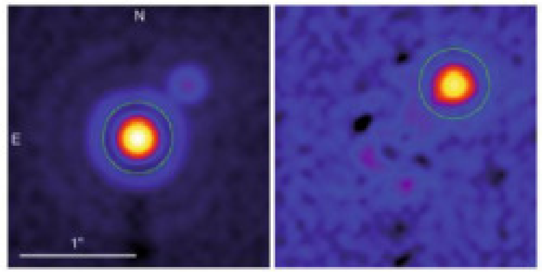


In 1978 the primary component A was reported to be a spectroscopic binary (sep. 0".6) in the Proceeding of the Australian Astronomical observatory (Tango et al., 1979), making the whole system quintuple. This was later confirmed by the Hipparcos satellite (0".736, Perryman et al., 1997). Being composed of two A-type in rapid rotation and one F-type main sequence stars, *δ Vel AB* is particularly interesting to astrophysicists, because of its close distance to the Sun.

With a revised Hipparcos parallax of 40.49 ± 0.39mas (van Leeuwen, 2007), it is just 80.6 light-years away. The outward components A and B have a wide orbit with a 142 year orbital period at an average distance of 49 AU. The primary component A has an apparent magnitude of 1.97, while the secondary component B is magnitude 5.55. Delta Vel C and D, two probable class M red dwarfs of magnitudes 11 and 13.5 at least 150 AU apart and orbit over a period of at least two thousand years.

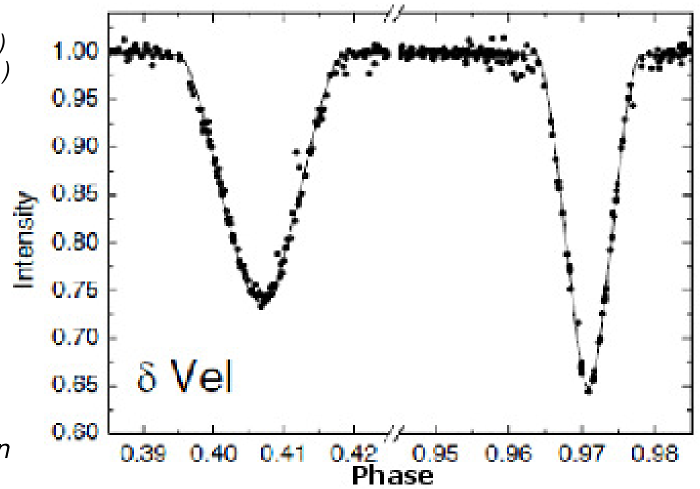
In 2000 it was announced that the components Aa and Ab form an eclipsing binary (Otero et al., 2000), having an orbital period of 45.150 days (a ~ 0.5 AU) and an eccentricity of 0.230 (Ammler-von Eiff, M., 2011). The system probably contains two early A-type stars (Otero et al., 2000). Surprisingly enough, Delta Velorum became one of the brightest known eclipsing binaries in the sky, one of the very few observable with the unaided eye. Although Algol has a deeper minimum and is much easier to observe visually.

Orbital period of 45 days seems to be remarkably long for most known eclipsing binaries. The δ Vel system is also noticeable for another reason. Because of precession (the 26,000-year wobble of the Earth's axis), δ Vel will be a South Pole star around 9000 AD. Being close to out Solar system, Delta Velorum therefore presents an unique opportunity to determine independently the physical properties of the three components of the system. The components Aa and Ab are bright fast rotating stars, with masses of 2.53*M*⊙ and 2.37 *M*⊙ (≈ 4% accuracy) respectively, and the mass of δVel B is estimated to be ≈ 1.5 *M*⊙.



Delta Vel A (left) and B (right). By Kervella, P.; Thévenin, F.; Petr-Gotzens, M. G. (2009)

Right: Detrended and filtered (removing obvious outliers) SMEI LC of Delta Velorum (Pribulla et al., 2011)



References for further reading:

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- Kervella, P. et al. 2009; A&A, 493, 107
- Pribulla, T. et al. 2011; A&A, 528, A21, 15
- Merand, A. et al.;2011; A&A, 532, 50
- Kervella, P. et al. 2013; A&A, 552, 18

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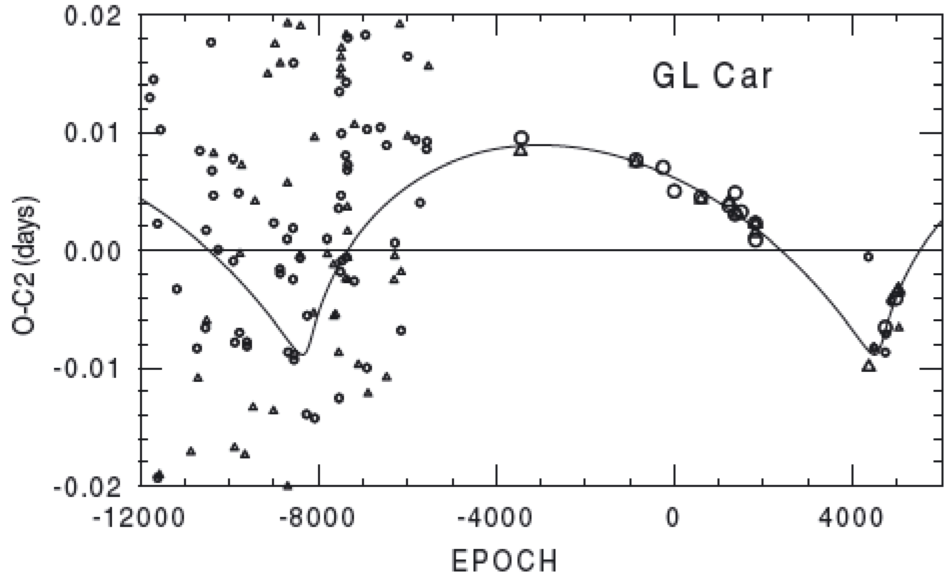

***Fig. 2.** The O–C2 diagram for the times of minima of GL Car after subtraction of the apsidal motion. The curve represents a light-time effect for the possible third body eccentric orbit with a period of about 90 yr and an amplitude of about 13 min. The individual primary and secondary minima are denoted by circles and triangles, respectvely* (Wolf et al., 2008).

There are some advantages and disadvantages of the use of this effect (Hegedüs et al. 2005):
Advantages:

- its basic study requires only very simple techniques (timing of eclipsing minima).
- the effect includes information not only about the internal mass distribution, but the gravitational theory itself as well.

Disadvantages:

- generally one needs to wait for quite a long time until the effect can be revealed;
- by the study of minima time observations (or by changes in the spectroscopic orbital elements), because the typical periods of this effect are from several hundred to several thousand years;
- the individual internal structure parameters remain unknown, only the weighted average of the two components can be determined.

A detailed analysis of the period variations can be performed using times of minimum light observed throughout the apsidal motion cycle, and from this both the orbital eccentricity and the period of rotation of the periastron can be obtained with a high accuracy. Moreover, this provides independent information for the analysis of the light curves (Giménez, 1994).

Similar photometric studies of apsidal motion in EEB's were published regularly during the seventies by Helmut Busch, Hartha observatory, and later e.g. by Kh. F. Khaliullin, Moscow University, or J. V. Clausen, Copenhagen University (Wolf et al., 2004). A catalogue of eclipsing binaries that are suitable for photometric monitoring was provided by Hegedüs (2000) while a catalogue of known binaries with apsidal motion was published by Petrova & Orlov (1999).

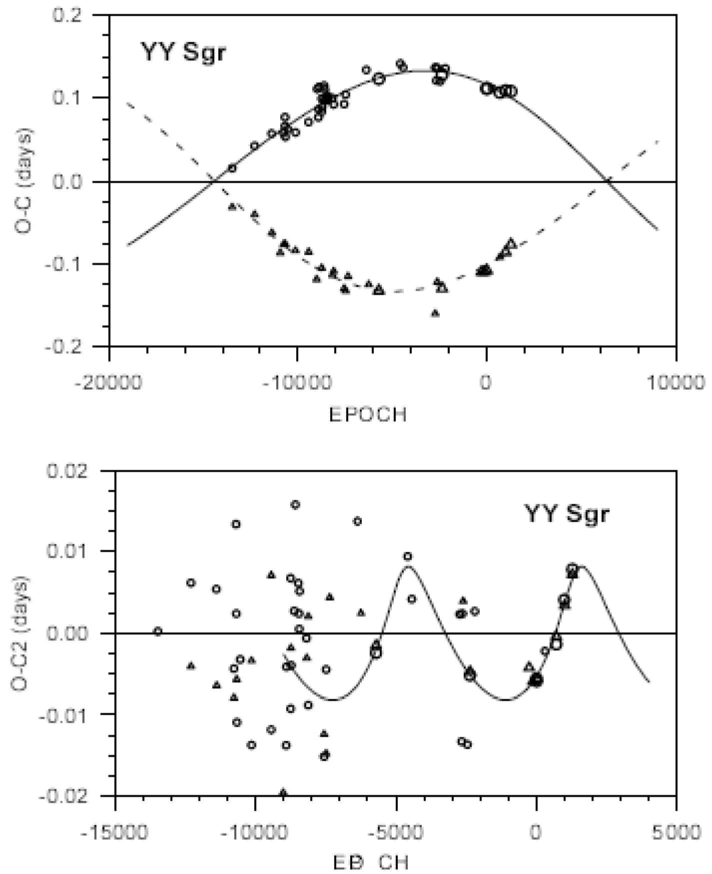

***Fig. 3.** O – C residuals for the times of minimum of YY Sgr with respect to the linear part of the apsidal motion equation. (top). Below is the O – C2 diagram for the times of minimum of YY Sgr after substraction the terms of the apsidal motion. The curve represents a light-time effect for the third body orbit with a period of 44 years with and an amplitude of about 0.008 days. (Wolf, 2000)*

The theory behind the effect

Suitable numerical methods for the apsidal motion analysis were described by Gimenez & Garcıa-Pelayo (1983), Lacy (1992), and Wolf & Šarounová (1995).

Below some basic concepts behind the core of the theory are provided just to recap of the method. There are five independent variables (T_0, P_s, e, ω_1, ω_0) determined in this procedure. e represents the eccentricity of an orbit. The periastron position ω at epoch E is defined by the famous linear equation:

$$\omega = \omega_0 + \omega_1 * E,$$

where ω_1 is the rate of periastron advance (in degrees per sidereal cycle or in degrees per year), and the position of periastron for the zero epoch T_0 is denoted as ω_0. On a shorter timescale, the precession of an eccentric orbit in its own plane can produce an observable rate of change in the longitude of periastron:

$$\omega_1 = d\omega / dt.$$

The sidereal and anomalistic periods of the binary, P_s and P_a, are connected by the following equation:

$$P_s = P_a\,(1 - \omega_1 / 360^\circ),$$

and the period of apsidal motion can be represented via

$$U = 360^\circ P_a / \omega_1$$

The rate of motion of the apsis is dependent on the internal structure of each component. Determination of the characteristics of a binary thus provides an observational test of the theory of stellar structure and evolution. The apsidal motion in relatively close binary systems can be studied by means of an O–C diagram analysis (for details see, e.g., Wolf *et al.* 1996, 1997).See Fig.2 and Fig.3 as examples of this kind of research.

In the case of deep, narrow eclipses the rate of apsidal motion can be determined by the analysis of primary and secondary eclipse timings and by measuring the change in the displacement of the secondary minimum from the half point (0.5 phase) according to

$$D = (t_2 - t_1) - P / 2$$

where t_2 and t_1 are times of secondary and primary minima, respectively (GM85). D, in turn is related to the longitude of periastron ω by the formula given by Sterne (1939, a, b):

$$D = \frac{P}{\pi}\left[\tan^{-1}\left(\frac{e\cos\omega}{(1-e^2)^{1/2}}\right) + \frac{e\cos\omega}{1-e^2\sin^2\omega}(1-e^2)^{1/2}\right]$$

For a short recap of the method: the individual equations for computing the time of primary and secondary minima are given in Giménez & García-Pelayo (1983). This is a weighted least squares iterative procedure, including terms in the eccentricity up to the fifth order.

Eclipsing Binary with Eccentric Orbits Catalog

In 2007 there was a catalog containing a list of binary systems with eccentric orbits published (Bulut+). The catalog lists the physical parameters (including apsidal motion parameters) of 124 eclipsing binaries with eccentric orbits. In addition, the catalog also contains ***a list of 150 candidate systems***, about which fewer details are known at present.

The catalog can be found at http://cdsarc.u-strasbg.fr/viz-bin/Cat?J/MNRAS/378/179

J/MNRAS/378/179 - Eclipsing Binary with Eccentric Orbits Catalog (Bulut I., Demircan O., 2007)

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Appendix 1. Examples of Eclipsing Binary Systems with Eccentric Orbits


V889 Aquilae, HD 181166


CW Cephei, SAO 20401


DI Herculis, SAO 86544


NY Cephei, SAO 20351


MZ Lacertae, SAO 12870


V402 Lacertae, SAO 51698


VW Pegasi, GSC 02753-00649


AR Cassiopeiae, SAO 35478

Object Designation		RA (J2000)	DEC (J2000)	Eccentricity	Period (days)	Mag. Range
V889 Aql	SAO 104708, HD 181166	19 18 49.8	+16 15 00	0.375	11.120879	8.52 - 9.1 V
AR Cas	SAO 35478, HIP 115990	23 30 01.9	+58 32 56	0.24	6.0663309	4.82 - 4.96 V
CW Cep	SAO 20401, HIP 113907	23 04 02.2	+63 23 48	0.29	2.72914	7.6 - 8.04 V
EY Cep	BD+80 112	03 40 04.0	+81 01 09	0.442	7.971438	9.8 – 10.57 V
NY Cep	SAO 20351, HIP 113461	22 58 39.8	+63 04 37	0.48	15.275727	7.4 - 7.55 V
Alpha CrB	SAO 83893, HIP 76267	15 34 41.3	+26 42 52	0.37	17.359907	2.21 - 2.32 B
V541 Cyg	GSC 02656-03703	19 42 29.4	+31 19 40	0.48	15.33779	10.2 - 10.9 p
V1143 Cyg	SAO 31850, HIP 96620	19 38 41.2	+54 58 25	0.54	7.6407613	5.85 - 6.37 V
NN Del	SAO 126201, HIP 102545	20 46 49.2	+07 33 10	0.518	99.2684	8.40 - 8.95 V
DI Her	SAO 86544, HIP 92708	18 53 26.2	+24 16 41	0.489	10.550168	8.39 - 9.11 V
LV Her	GSC 02076-01042	17 35 32.4	+23 10 30	0.61	18.435935	10.9 - 11.3 p
MZ Lac	SAO 12870, HIP 17257	22 28 01.7	+53 41 00	0.42	3.158795	11.2 - 12.1 p
V345 Lac	GSC 03986-02900	22 18 43.3	+54 40 33	0.456	7.491862	11.1 - 11.7 p
V402 Lac	SAO 51698, HIP 109354	22 09 15.2	+44 50 47	0.379	3.7820	6.7 - 6.99 Hp
V2283 Sgr	HD 321230	18 04 38.8	-36 54 52	0.488	3.4714231	10.23 -11.03 V
RU Mon	BD-07 1623, HIP 33163	06 54 12.3	-07 35 45	0.396	3.584749	10.33 -11.18 V
FT Ori	SAO 78120, HD 42858	06 13 58.1	+21 25 39	0.405	3.150415	9.1 - 9.9 V
VW Peg	GSC 02753-00649	22 56 23.6	+33 13 43	0.39	21.071749	9.9 - 10.6 V
V436 Per	SAO 22690, HIP 8704	01 51 59.3	+55 08 50	0.388	25.9359	5.49 - 5.85 V
EQ Vul	HD 337188, SON 4475	19 58 23.2	+28 01 08	0.359	9.297164	11.79 - 12.5 B